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None

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(54) **Microwave load cell**

(57) Two modes of oscillation are excited simultaneously in a microwave resonator, the frequencies being determined by the size and shape of the resonator. The distortion of the resonator by the applied load causes the two frequencies to change in different ways. Signals from both oscillations are combined at the output, generating a beat frequency which is a measure of the applied load. Resonators of various shape are described together with the corresponding useful modes of oscillation.

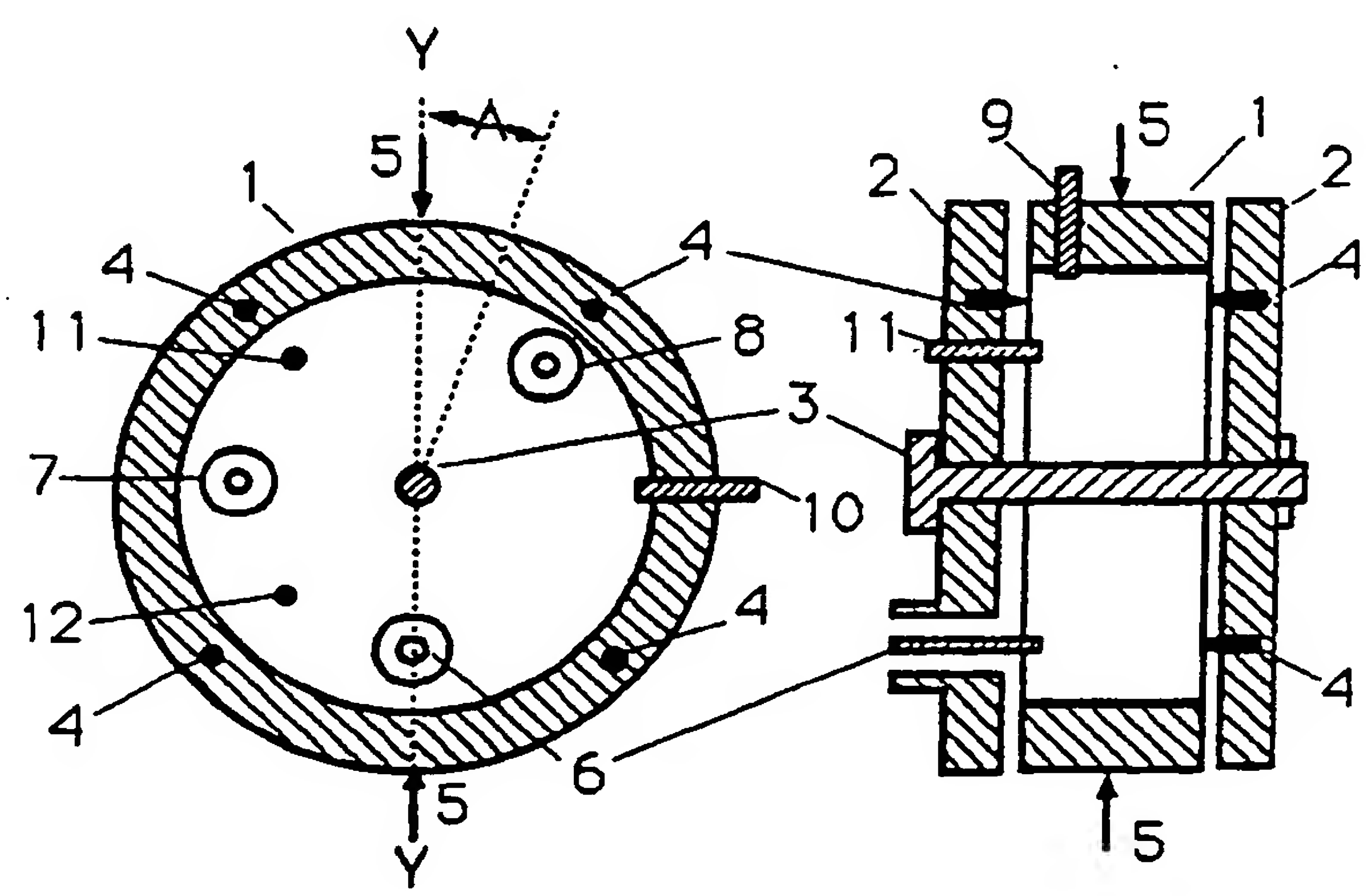

Fig. 1

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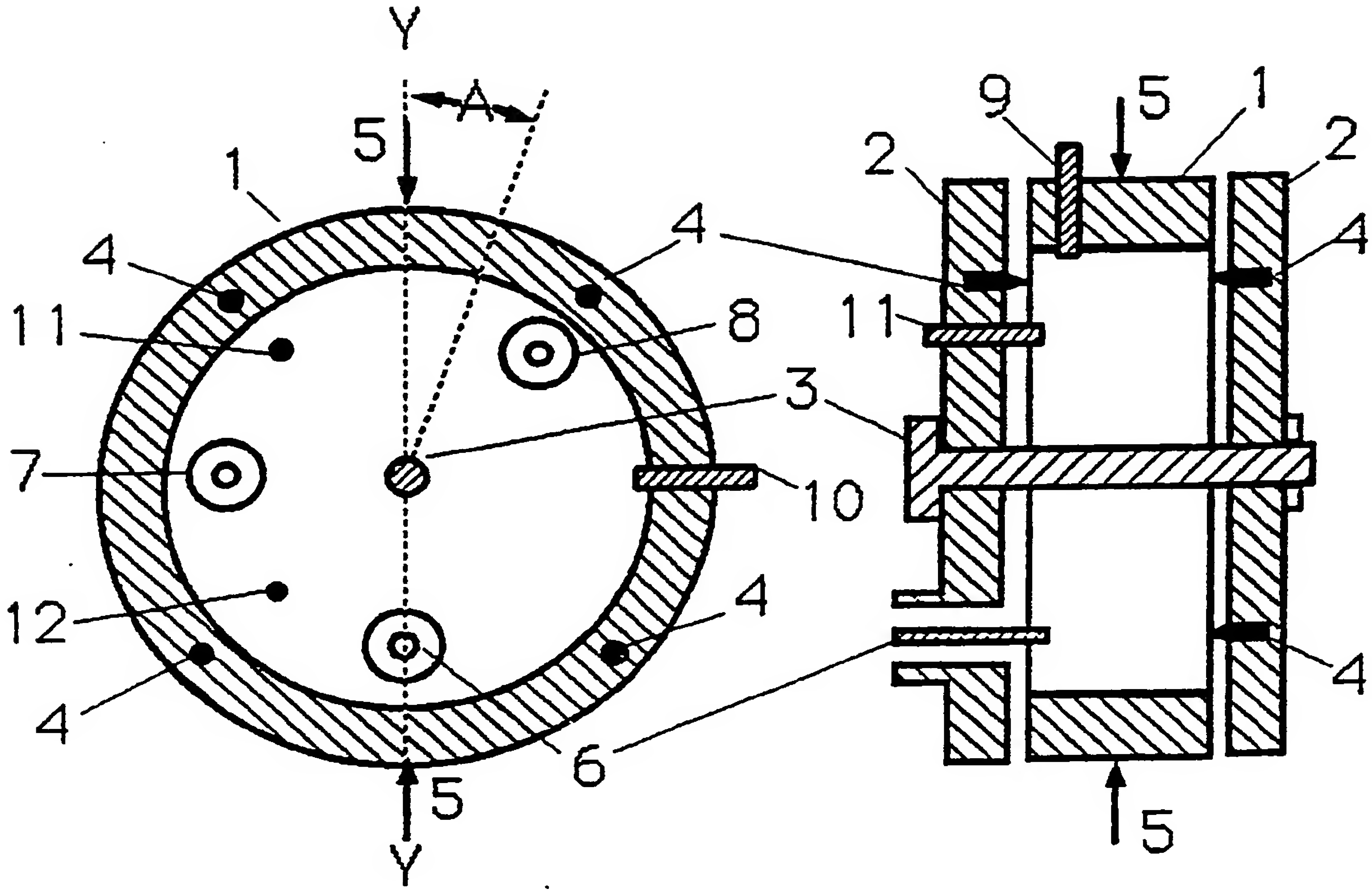

Fig. 1

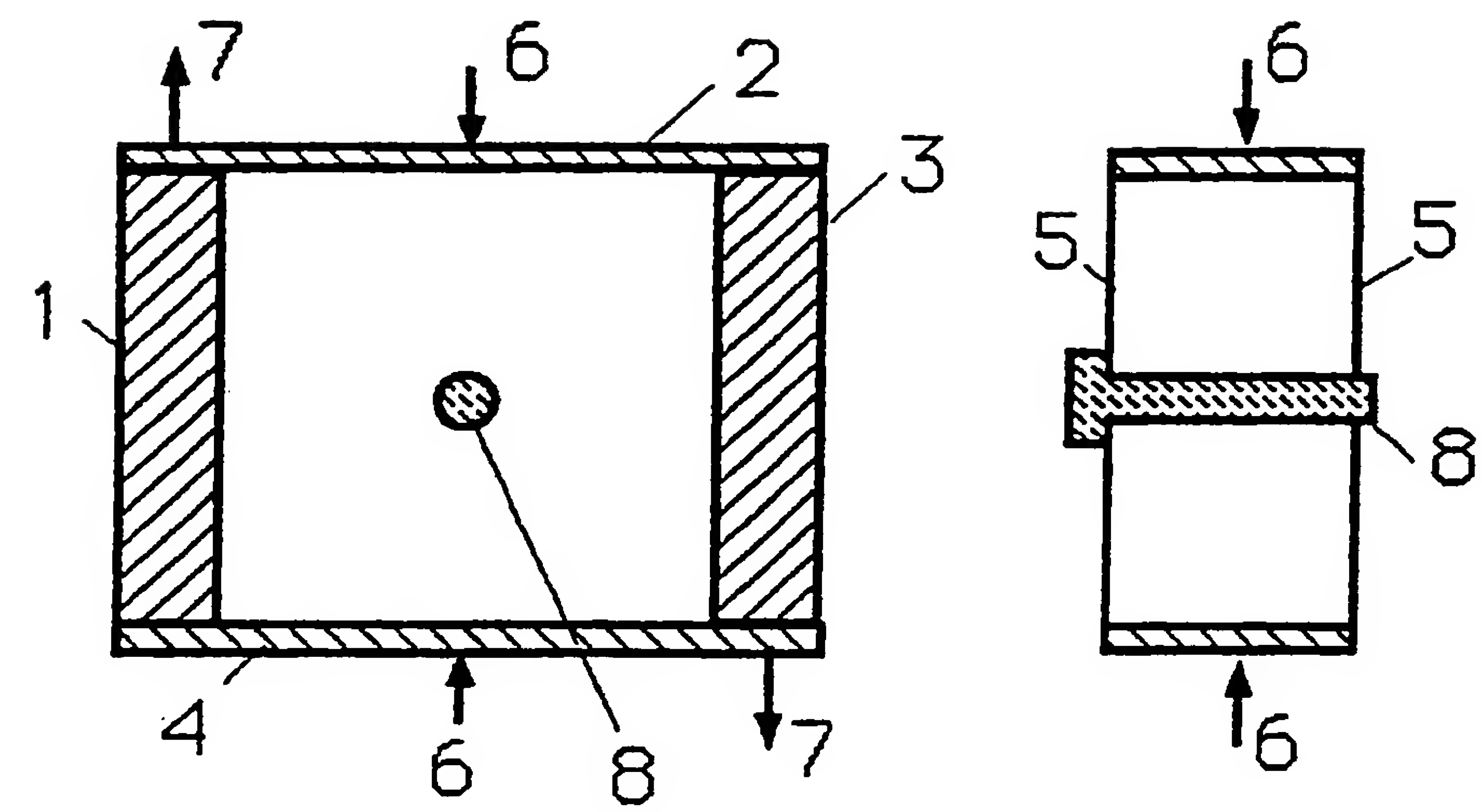

Fig. 2

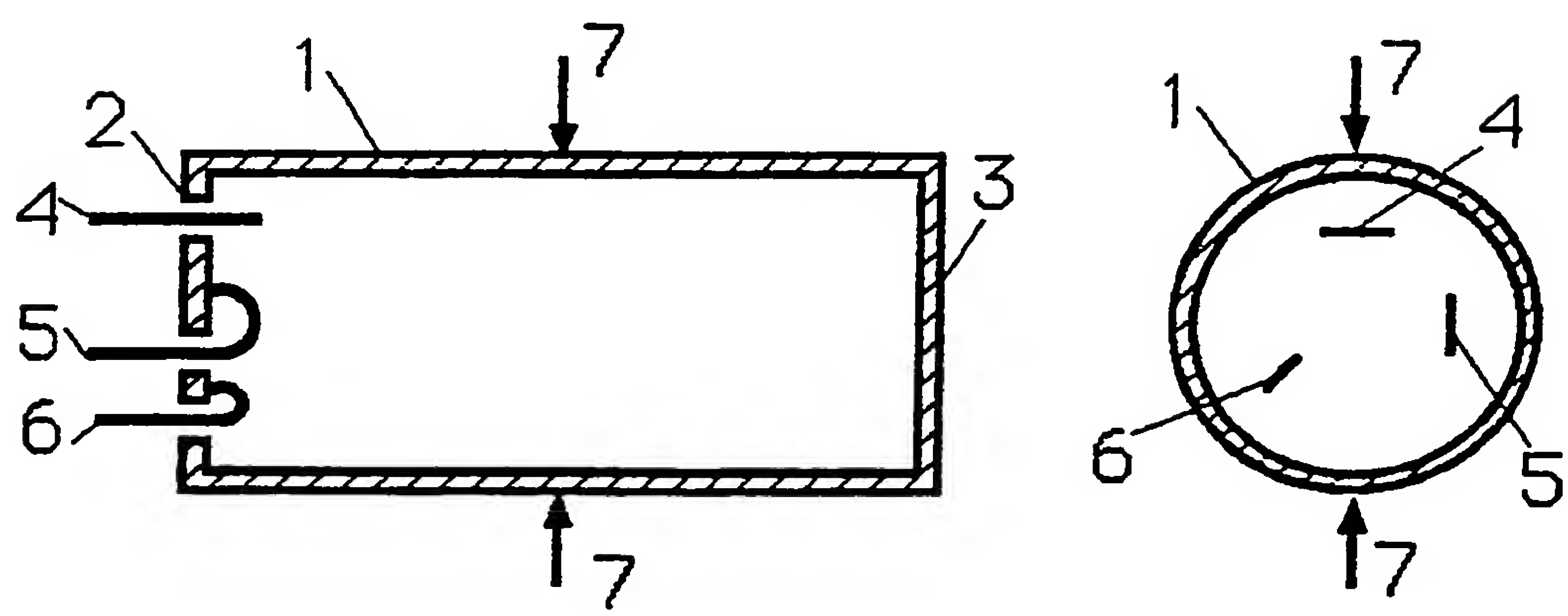

Fig. 3

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MICROWAVE LOAD CELL

This invention relates to a transducer giving an electrical signal the frequency of which is a measure of the applied load.

The measurement of compressive or tensile forces is usually carried out by means of a load cell, in which an appropriate mechanical structure is distorted by the load, and the distortion is measured by strain gauges. Conventional strain gauges give a small signal (of order millivolts) and require sensitive d.c. amplifiers. Moreover the output is an analogue signal and accuracy requires stability in all components.

According to the present invention the load to be measured is applied to a microwave resonator in which two modes of oscillation have been excited by microwave amplifiers. The frequencies of the oscillations are determined by the dimensions and shape of the resonator. The distortion of the resonator by the load causes the frequencies of the two oscillations to diverge. Both frequencies are combined at the output terminal, setting up a beat signal with frequency equal to the difference between the frequencies of the two modes. The frequency of the beat signal is then a measure of the applied load.

The invention comprises a microwave resonator, means for exciting two simultaneous oscillations and means for combining signals from the two oscillations at the output, with the

effect that the beat frequency is a measure of the applied load. The resonator may be a hollow metal volume of any suitable shape, or alternatively a dielectric volume of suitable shape.

The invention is suitable for measuring compressive loads, tensile loads, or shear loads.

A particular embodiment of the invention will now be described by way of example with reference to figure 1 which shows two elevation views of the load cell. In this embodiment the resonator comprises a circular metal annulus 1 bounded by metal side plates 2. The load to be measured is applied to the annulus either in tension or compression along the major axis YY by means of mechanical connections 5, and sets up a small elliptical distortion of the annulus. Each side plate is located on the annulus by four needle bearings 4, so placed that there is no mechanical interference between the side plates and the load bearing annulus in respect of the distortion of the annulus by the load. The spacing between the side plates 2 and the annulus 1, as determined by the needle bearings 4, is very small in order to minimize microwave leakage from the cavity. The side plates are held onto the annulus by means of the central bolt 3.

Microwave connection to the cavity is provided through the loosely coupled coaxial probes 6, 7 and 8, of which only 6 is shown in detail in the right hand elevation of figure 1. A microwave amplifier with positive feedback is connected to probe 6 in such a way that an E_1-mode of oscillation is

excited in the cavity, the radio frequency electric field in the cavity being given by $J_1(kr).\cos(A)$ in which expression A is the angle shown in figure 1 and the other symbols have their conventional meaning. This mode of oscillation is referred to as 'mode 1' and has frequency f_1, which is almost exclusively determined by the dimensions and shape of the cavity. A similar amplifier is connected to probe 7 and sets up an independent oscillation, referred to as 'mode 2', with frequency f_2 and with electric field given by $J_1(kr).\sin(A)$. Note that the E_0-mode is suppressed by the presence of the bolt 3.

If the cross section of the cavity is exactly circular mode 1 and mode 2 have exactly the same frequencies, i.e. $f_1 = f_2$. But when the cavity is compressed along the axis YY, frequency f_1 increases and frequency f_2 decreases. At the output probe 8 both signals are present with approximately equal amplitudes and a rectifying detector connected to probe 8 generates an output signal of frequency f_0 equal to the difference frequency, i.e. $f_0 = f_1 - f_2$. The frequency f_0 at the output is a measure of the applied load. For a tensile load applied along the axis YY the action is similar but in this case f_2 is greater than f_1. Instead of using probe 8, the combined output signal may alternatively be taken directly from the two microwave amplifiers external to the cavity using suitable connections.

The resonator is further provided with adjusting screws indicated in figure 1 at 9, 10, 11 and 12. The function of these adjusting screws will now be described. Screw 9 allows

the frequency f_1 of mode 1 to be adjusted. Similarly screw 10 adjusts the frequency f_2 of mode 2. Screw 11 introduces a coupling between modes 1 and 2. Screw 12 likewise introduces a coupling between the modes, but with opposite sign. Therefore screws 11 and 12 can be used to compensate any undesirable coupling between the modes which may accidentally be present.

Another embodiment of the invention will now be described by way of example with reference to figure 2. In this embodiment the resonator is a cavity comprising a square metal frame with side members 1 and 3, and top and bottom members 2 and 4. The faces of the frame are closed by sheets of metal gauze or sheets of corrugated metal 5 which do not interfere mechanically with the distortion of the frame under load. The load to be measured is applied either in compression or tension to the centre of the frame at the points indicated by the arrows 6. Two loosely coupled microwave amplifiers are used as described above to excite the E_{120} and the E_{210} modes in the cavity, the frequency of each mode being almost entirely determined by the size and shape of the cavity. The beat frequency between these oscillations is detected and is a measure of the load. As in the previous embodiment unwanted modes are suppressed by the central metal bar 8.

Alternatively in this embodiment the load to be measured is applied to the side members, for example downwards on side 3 and upwards on side 1 as indicated by the arrows 7, so as to distort the frame in shear. In this case the two modes of

oscillation excited by the amplifiers are the linear combinations $E_A = E_{120} + E_{210}$ of frequency f_A and $E_B = E_{120} - E_{210}$ of frequency f_B. The beat frequency between f_A and f_B is detected and is a measure of the applied load. This arrangement is mechanically convenient for applications to weighing machines.

In third embodiment now to be described by way of example with reference to figure 3 the resonator comprises a metal tube 1 of circular or square cross-section, closed at each end by metal plates 2 and 3. Two microwave amplifiers are coupled to the cavity by means of coupling loops 4 and 5 lying in mutually perpendicular planes, so that they excite two independent modes of oscillation with orthogonal polarizations, the frequencies of the oscillations being determined by the size and shape of the cavity. The loops 4 and 5 may be in the same end plate as shown in figure 3 or alternatively in opposite end plates. (Alternatively the same two modes may be excited by probes coupling through the walls of the tube 1). A third coupling loop 6 in a plane at 45 degrees to the others may be used to obtain a signal from both modes and used to generate the beat frequency. The load to be measured is applied to the centre of the tube as indicated by the arrows 7. The distortion of the tube at the centre changes the frequency of the two oscillations and generates a beat frequency which is a measure of the applied load.

In this embodiment the tube may be of square cross-section and the two modes of oscillation excited so that their polarizations are along opposite diagonals of the square. In

this case a beat frequency is generated when the sides of the tube are loaded at its centre ~~as indicated by the arrows 5~~ so as to distort the cross-section in shear, the beat frequency again being a measure of the applied load.

In all embodiments the two modes of oscillation may be excited simultaneously by a single microwave amplifier, the other principles of operation remaining the same.

CLAIMS

1 A load cell comprising a microwave resonator in which two modes of oscillation are excited simultaneously and the beat frequency between the two oscillations is used as a measure of the applied load.

2 A load cell as in claim 1 in which the resonator is a hollow metal cavity of any shape or a dielectric volume of any shape.

3 A load cell as in claims 1 or 2 in which the resonator is a hollow metal cavity with fourfold rotational symmetry such that the shape is unchanged by rotation through 90 degrees about the principal axis.

4 A load cell as in claims 1, 2 or 3 in which the two modes of oscillation are identical apart from a rotation of the pattern of internal electric and magnetic fields through 90 degrees about the principal axis.

5 A load cell as in claims 1, 2, 3 or 4 in which the cavity is a right circular cylinder with or without a central rod along the axis, and the load is applied across a diameter either in compression or tension, or tangentially perpendicular to a diameter in shear.

6 A load cell as in claims 1, 2, 3, 4 in which the cavity

is a rectangular parallelepiped of square cross-section and the load is applied either in compression or tension or parallel to the sides so as to distort the cavity in shear.

7 A load cell as in claims 1, 2, 3, 4, 5 or 6 in which the microwave oscillations are excited by one or more microwave field effect transistors and the beat frequency is detected with the use of a solid state diode.

8 A load cell as in claims 1, 2, 3, 4, 5, 6 or 7 in which adjusting screws are provided to regulate the frequency of the oscillations and the coupling between the modes.

9 A load cell substantially as described herein with reference to figures 1-3 of the accompanying drawings.

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